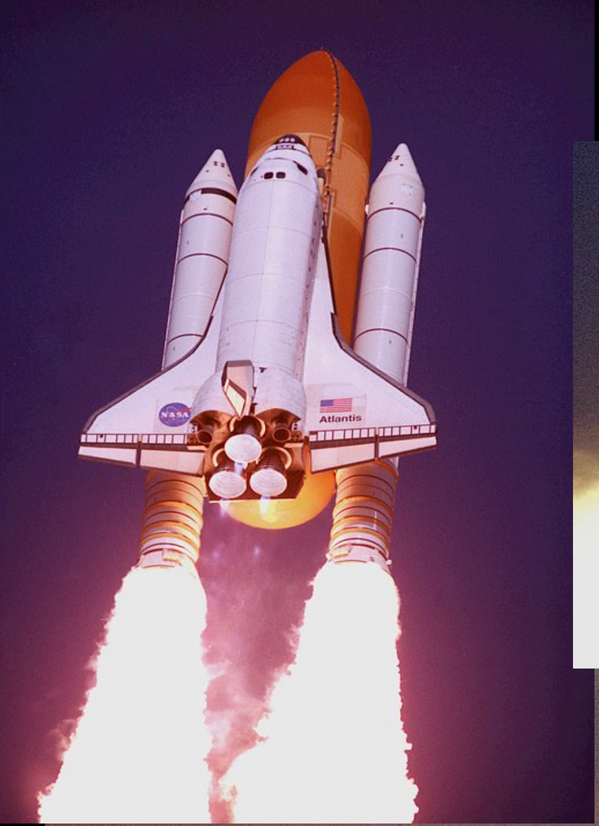
NASA Project Management Conference
University Park Maryland
March 30-31, 2004




# *The Challenge of Safe Return of the Space Shuttle to Flight*

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Space Shuttle Program
Deputy Manager

# Program Management Challenges to the Safe Return of the Space Shuttle to Flight

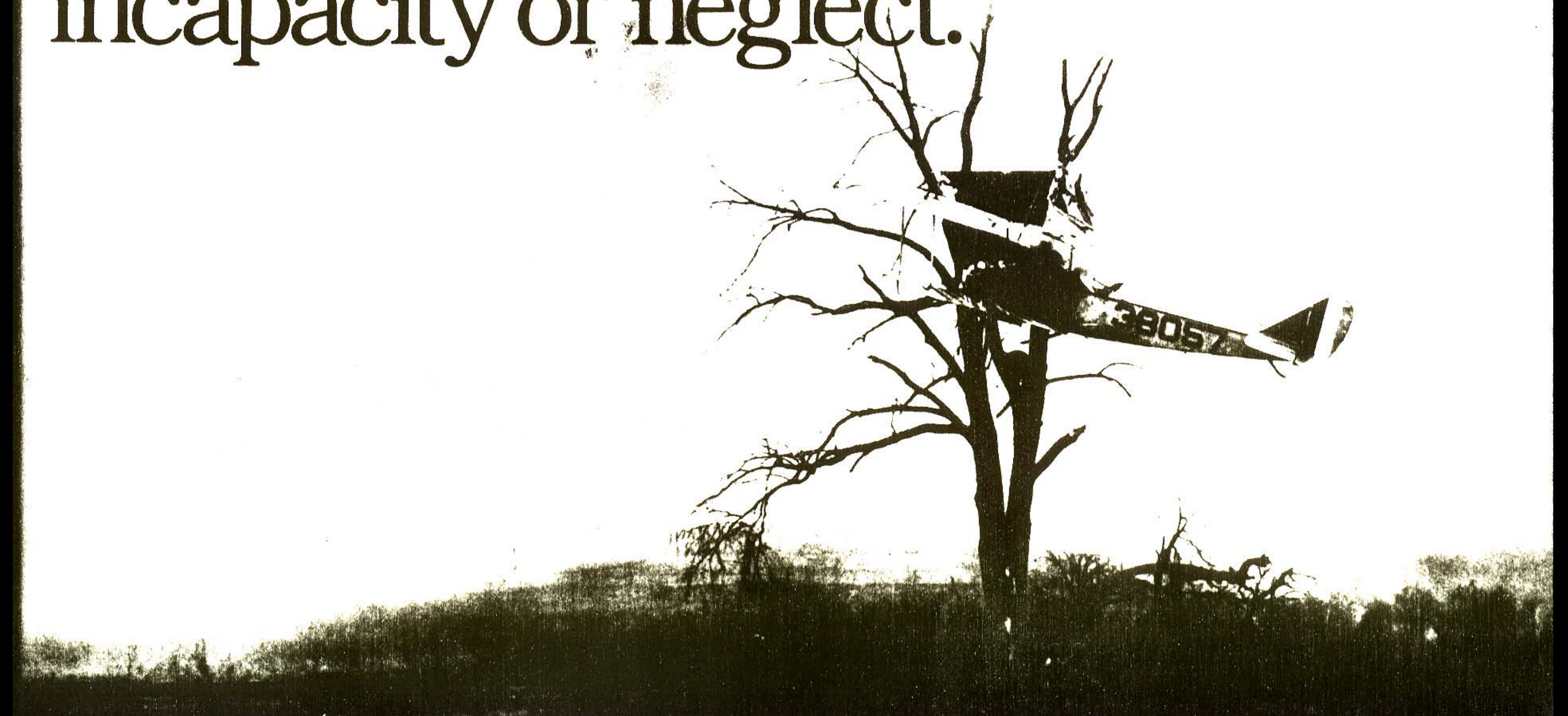
- Columbia Accident
- Complexity of the Problem
- Technical Challenges
- Cultural and Organizational Challenges
- Classical Project Management Tradeoffs
- Conclusion

# Program Management

Classic Program Management has 3 components
Cost, Schedule, and Content

- This is an usual project management time for the Shuttle Program
- Cost is a significant concern
  - Operations have ceased and all operating funds and personnel are available for Return to Flight work
- Schedule is not a driver
  - Desirable to fly as soon as practical to support the International Space Station (ISS)
  - Schedule is set from technical milestones
- Content is the only significant management concern
  - How safe is safe enough?
  - When have we done enough?
  - How can we prove it?

Aviation in itself is not inherently dangerous. But to an even greater degree than the sea, it is terribly unforgiving of any carelessness, incapacity or neglect.

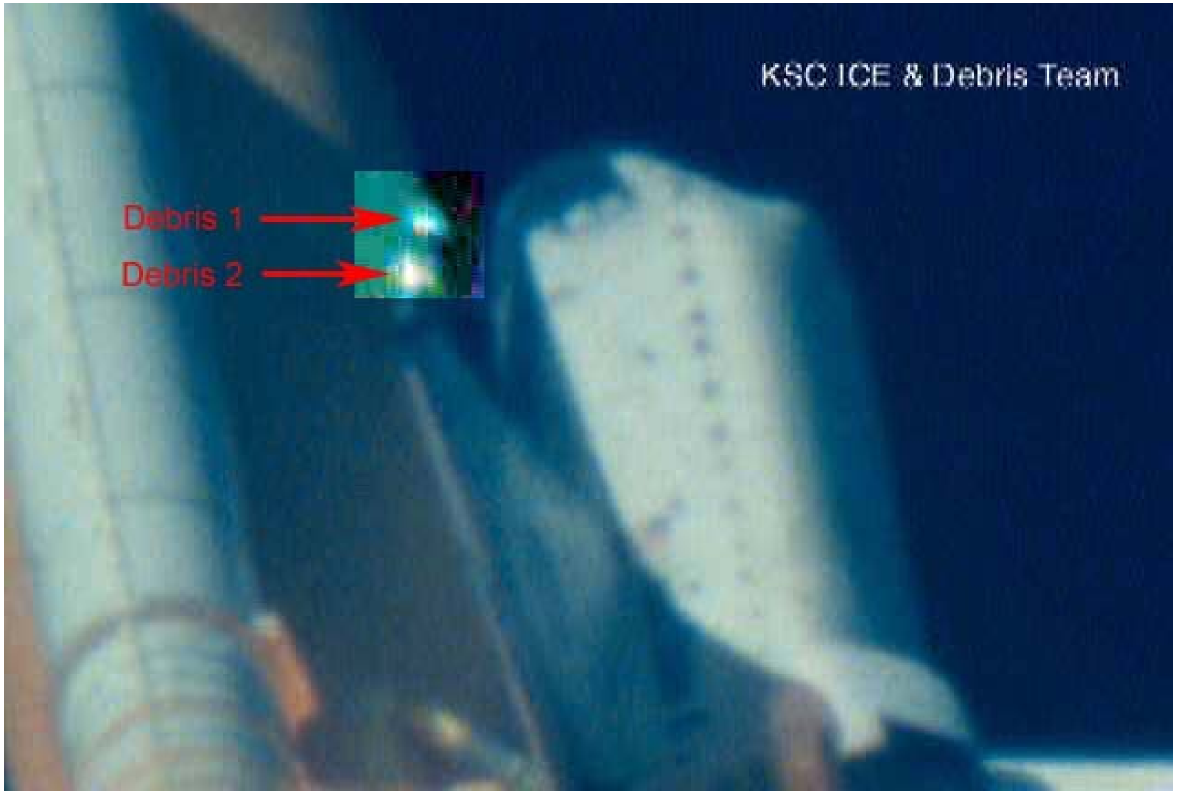


# CAIB Accident Scenario

- Post-launch photographic analysis determined that External Tank left bipod foam impacted Columbia's left wing

- The foam impacted in the vicinity of RCC panels 5 thru 9 at 81.9 seconds after launch

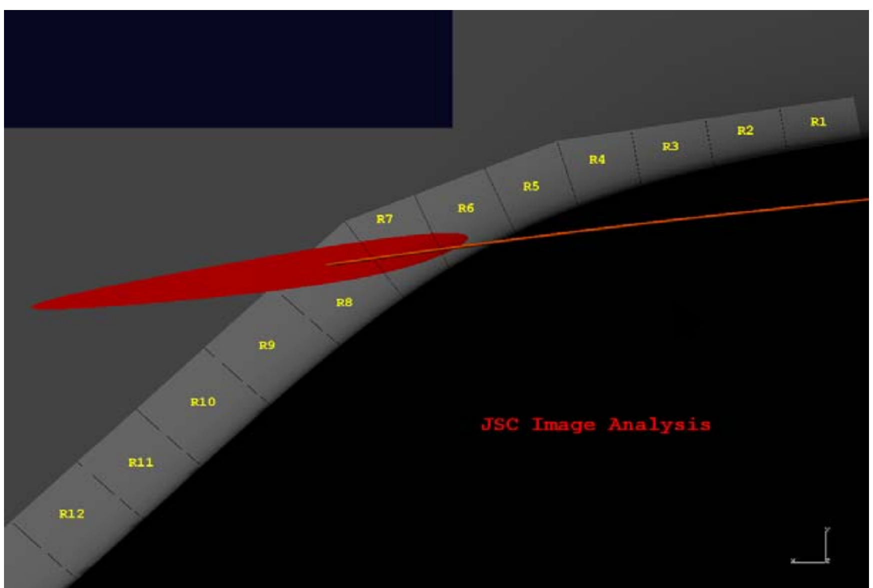
- The orbiter was at an altitude of 65,860 feet, traveling at Mach 2.46 at time of impact

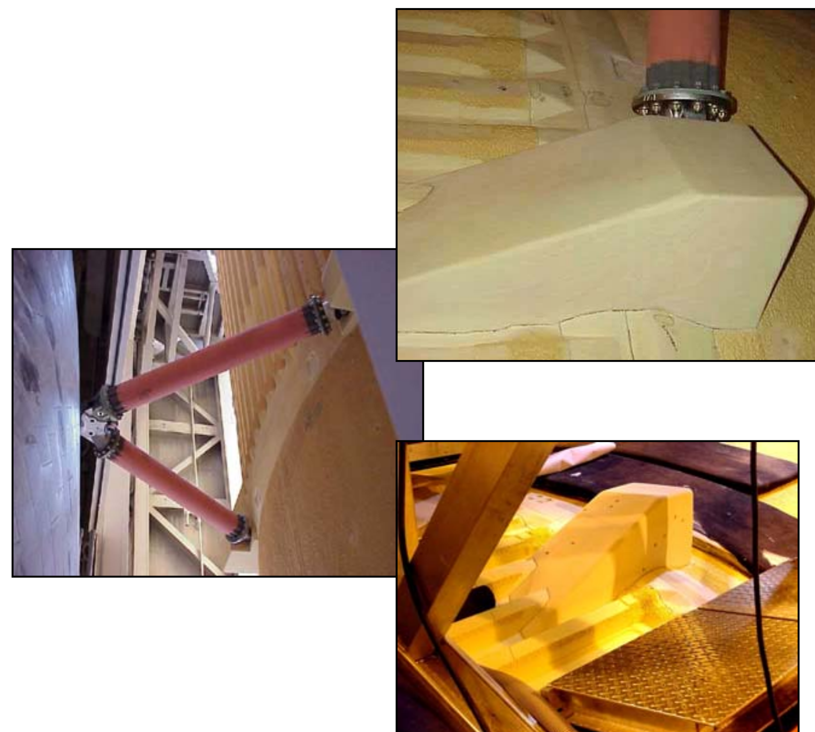


# CAIB Accident Scenario

- The best estimate of the foam size, based on imagery measurements, was 21 to 27 inches long and 12 to 18 inches wide

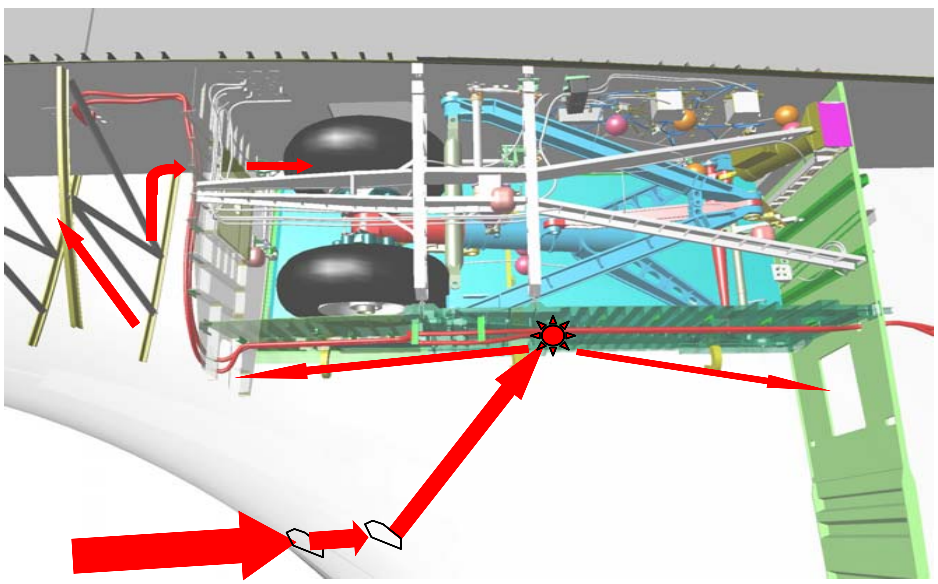
- There was sufficient visual and debris trajectory information to implicate the left bipod ramp area as the source of debris



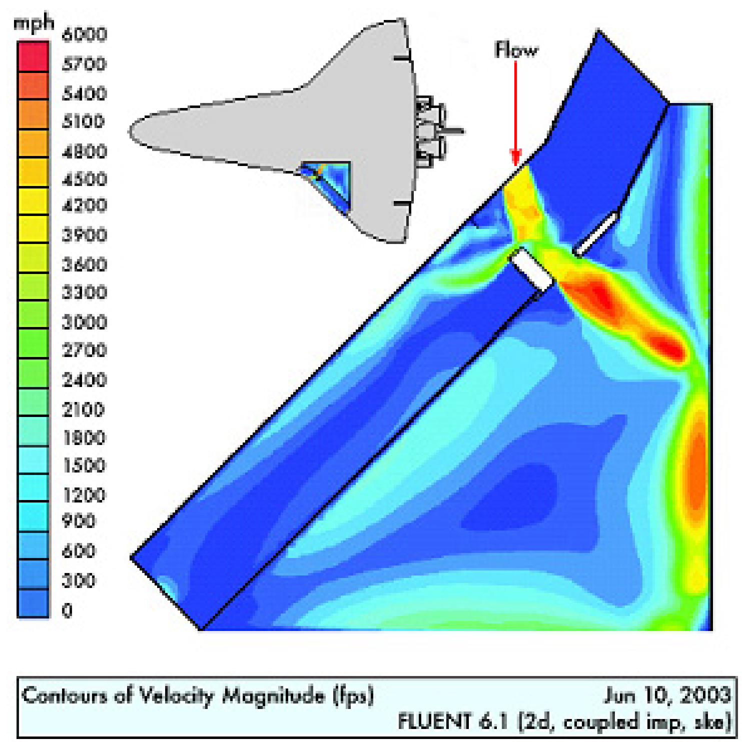



# CAIB Accident Scenario

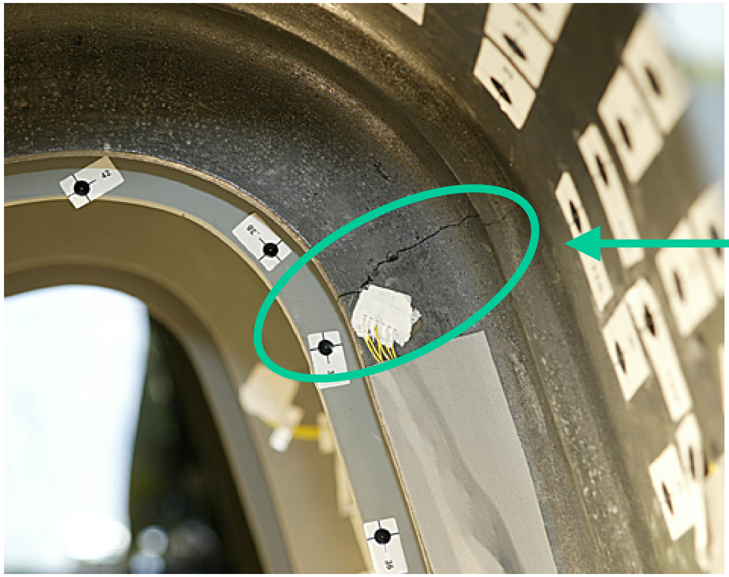
- Eventually the vehicle motion was too great for the flight control system to manage, leading to loss of vehicle control and aerodynamic break-up



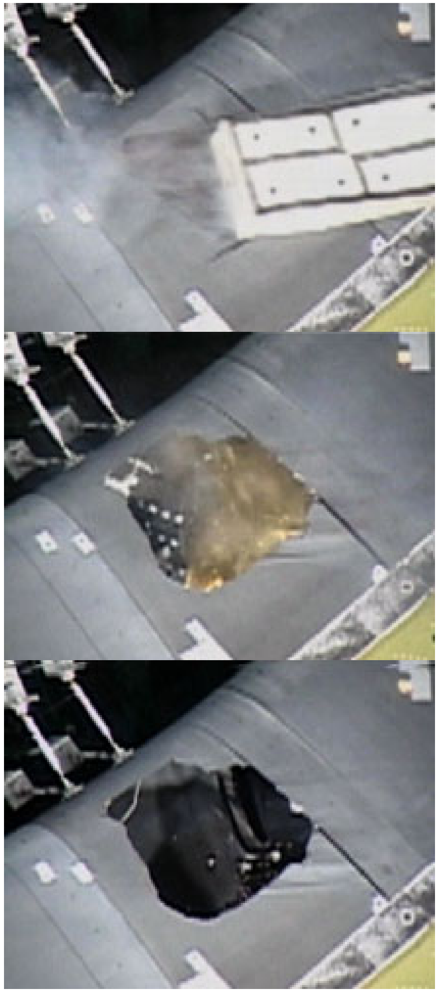
Hot gas breaches the wheel well



# RCC Impact Testing June – July 2003 Confirms Accident Scenario



- Initial foam impact test on RCC Panel # 6 results in a panel rib crack



- Five (5) Fiberglass panel tests were conducted to provide additional model output information

- RCC Panel # 8 was tested on July 7, 2003; the 1.67 pound piece of foam impacted at approximately 775 ft/sec; resulting in a 16 inch diameter hole

# *Columbia* Board Recommendations

## Critical Path Drivers


**29 Recommendations in the Following Categories:**

- Improve Thermal Protection System Monitoring and Repair
- Fix Debris Shedding from the External Tank
- Improve Vehicle Imaging Capability
- Qualify the Bolt Catcher Separation Mechanism
- Improve Flight Hardware Closeout Documentation
- Improve the Foreign Object Debris Program
- Improve MMT Training
- Launch Schedules Consistent with Resources
- Upgrade Orbiter Sensor Data
- Create an Independent Technical Engineering Authority
- Upgrade Closeout Photo Process
- Improve Wire Inspection Techniques
- Re-Certify the Shuttle for Flights beyond 2010

# External Tank

# Return To Flight (Rtf) Planning

## External Tank Certification


- Forward Bipod Ramps Redesigned
  - Spray on Foam eliminated
- Liquid Oxygen (LO2) Feedline Bellows Modified
  - Thermal protection System drip lip added
- Nondestructive testing procedures being developed
  - Eliminate critical defects in foam applications

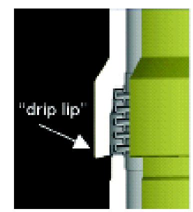

STS-50 Bipod Foam Loss

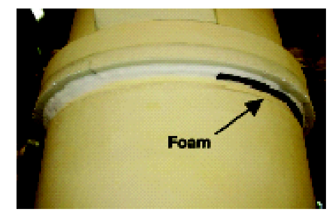

Bipod Foam Ramp


Redesigned Bipod Fitting

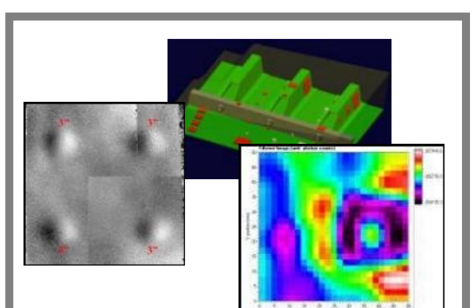

LO2 Feedline Bellows

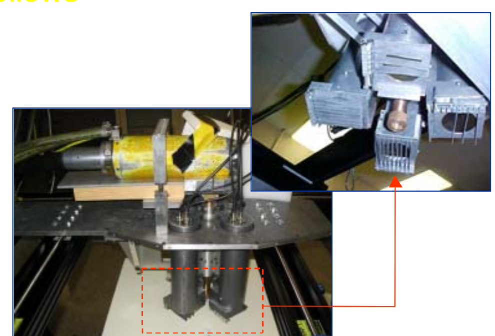
Condensate drain "drip lip"




Condensate drain "drip lip" with foam insert

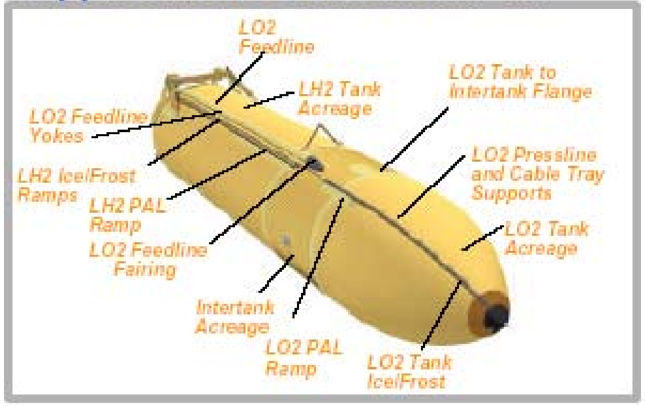

NDE Development

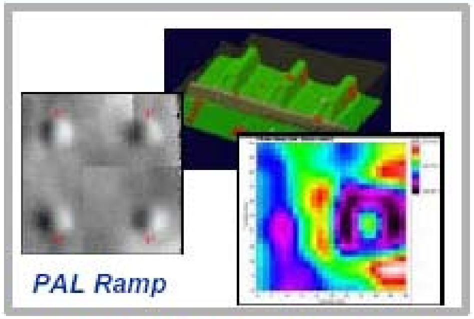

Backscatter


Terahertz

# ET Return to Flight Baseline

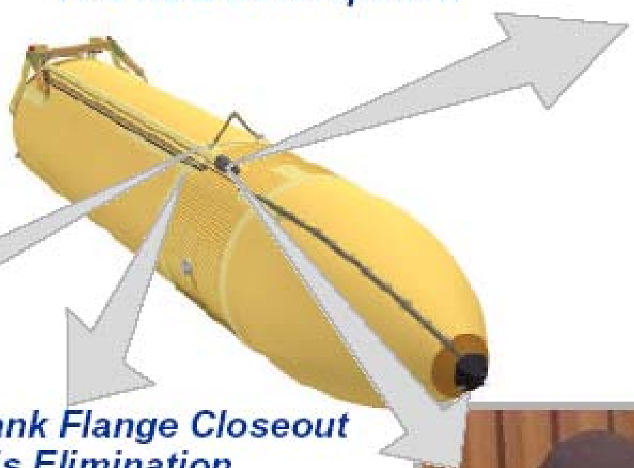
## As-Built Critical TPS Application Certification Plan




## TPS NDE Development

## Redesigned Bipod Fitting



## LO2 Feedline Bellows Ice

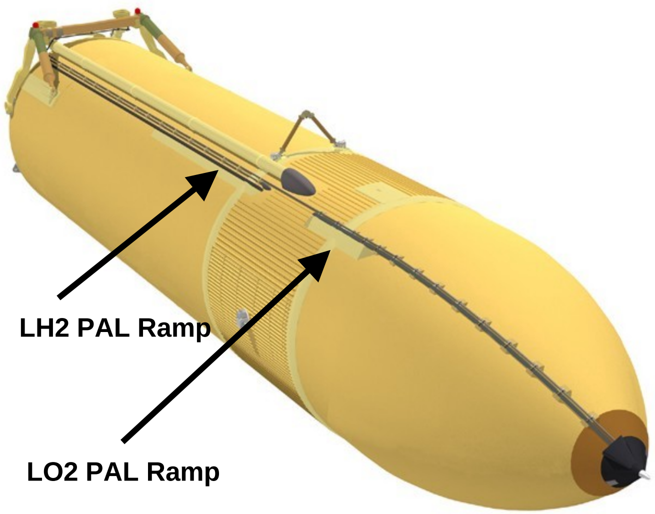
## LH2 / Intertank Flange Closeout Debris Elimination

## ET Camera (Enhanced In-flight Imagery)


# RTF Planning

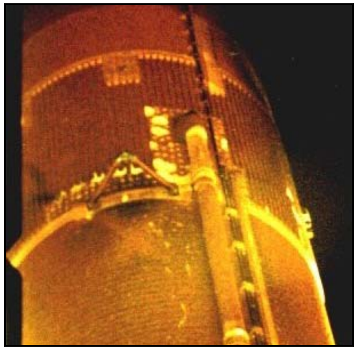
## External Tank Certification

- Nondestructive Evaluation (NDE) testing adds confidence to critical debris elimination plan



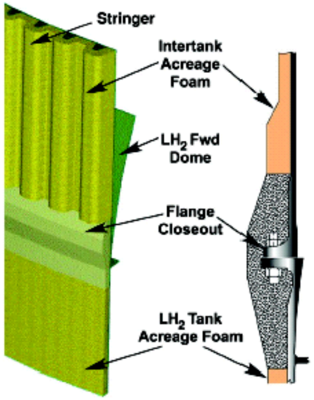

- Protuberance Airload (PAL) Ramp foam - certified by NDE testing

- Liquid Hydrogen Intertank Flange
  - Critical debris size and transport mechanism studies continue on the critical path for return to flight

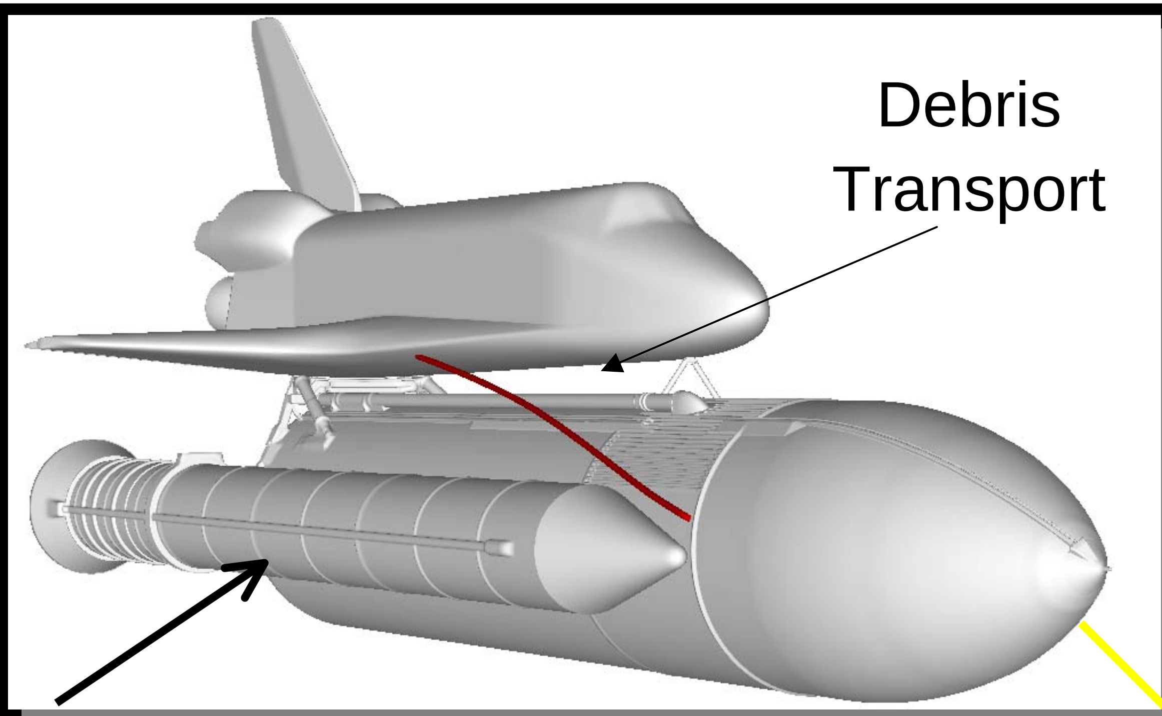


STS-26 Intertank Flange Foam Loss

Intertank Flange



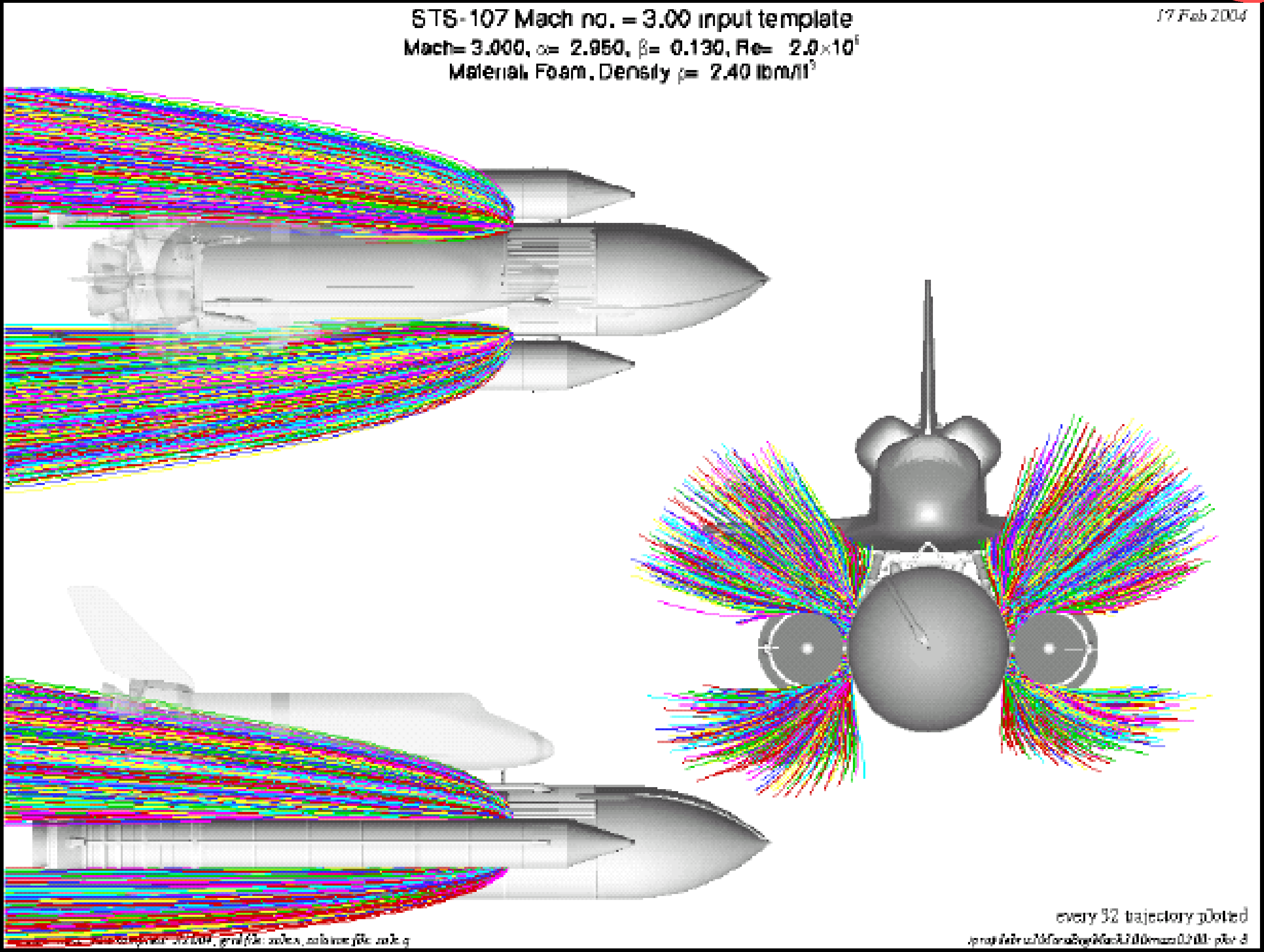
# Debris Impact Environment Process




Debris Source


Damage Assessment

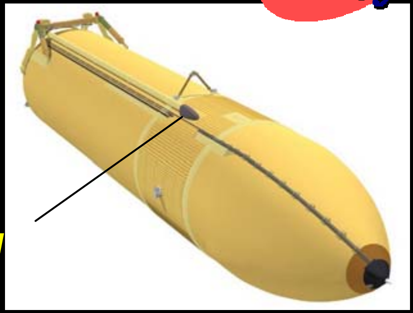
# Debris Impact Environment

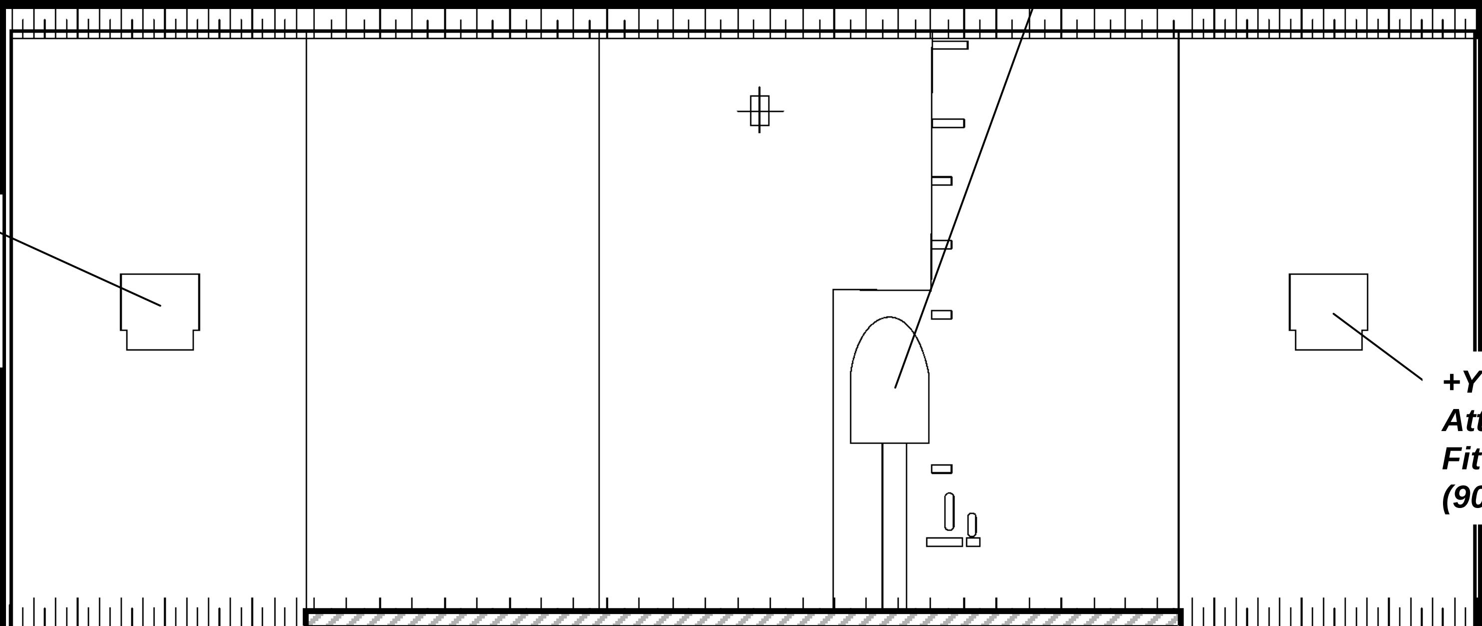


# Liquid Hydrogen Intertank Flange

## Critical Debris Zone

- Critical debris zone previously identified as +/-67.5° from Z axis, Orbiter side of tank



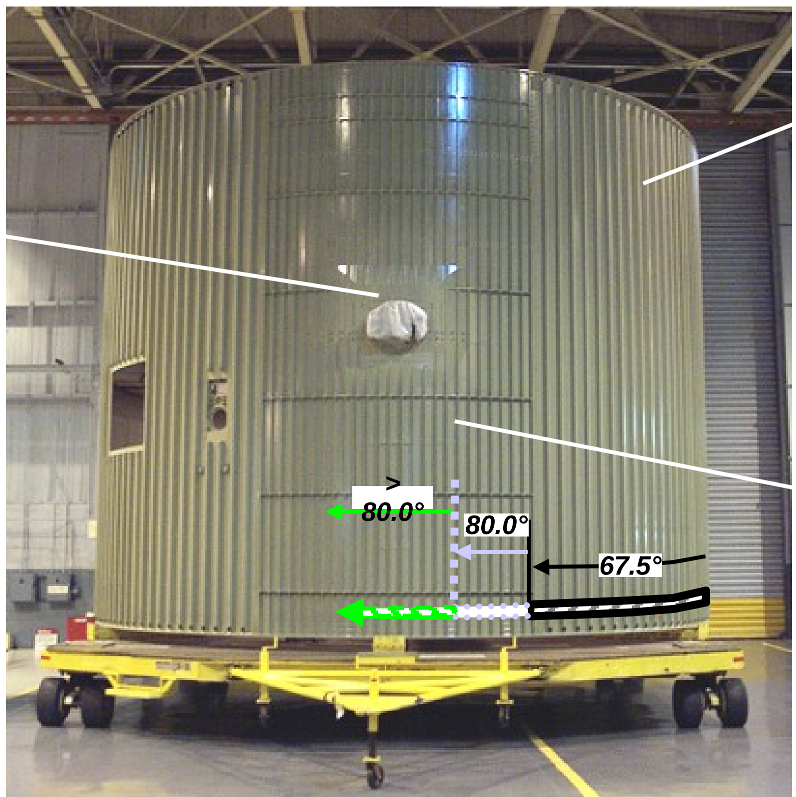

*+Z Stringer Panel, Area originally identified for removal/ replacement with enhanced closeout*

# Impact of Extended

## Critical Debris Zone

- ET currently removing the Intertank/LH2 tank flange closeout in the specified zone – Skin/stringer substrate configuration
  - Replacing closeout with enhanced, verified and validated process
- Removal of additional closeout required due to increase in zone
  - Different substrate configuration (machined ribs) in extended zone

*-Y SRB Fitting*




*Intertank Substrate Configuration*

***Skin/Stringer Panel***
*(Lower flange area originally identified for removal/ replacement with enhanced closeout)*

***Thrust Panel***
*(Additional lower flange closeout removal required due to extended critical debris zone)*

***Critical Debris Zone(s)***

***67.5° from +Z***

***80.0° from +Z***

***> 80.0° from +Z***

# RTF Planning

## Improved Ascent Imagery

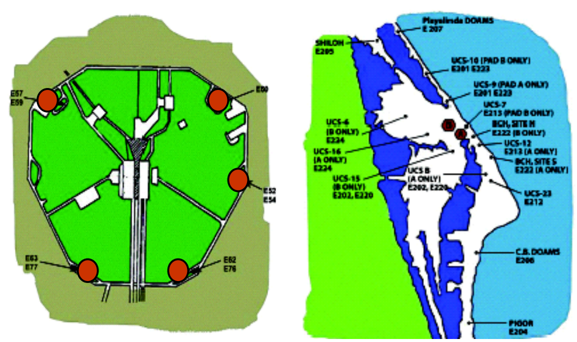
- Detection on ascent improved by using integrated approach
- Additional Ground-Based trackers added and all upgraded
- Aircraft and ship-based support under consideration
- Digital cameras on External Tank, Solid Rocket Booster, and Orbiter improve real-time assessment
- Handheld crew cameras support added systems

Proposed STS-114

Camera Locations


SRB Mounted Camera

ET Mounted Camera



Short, Medium and Long-Range Trackers

Ground Tracking

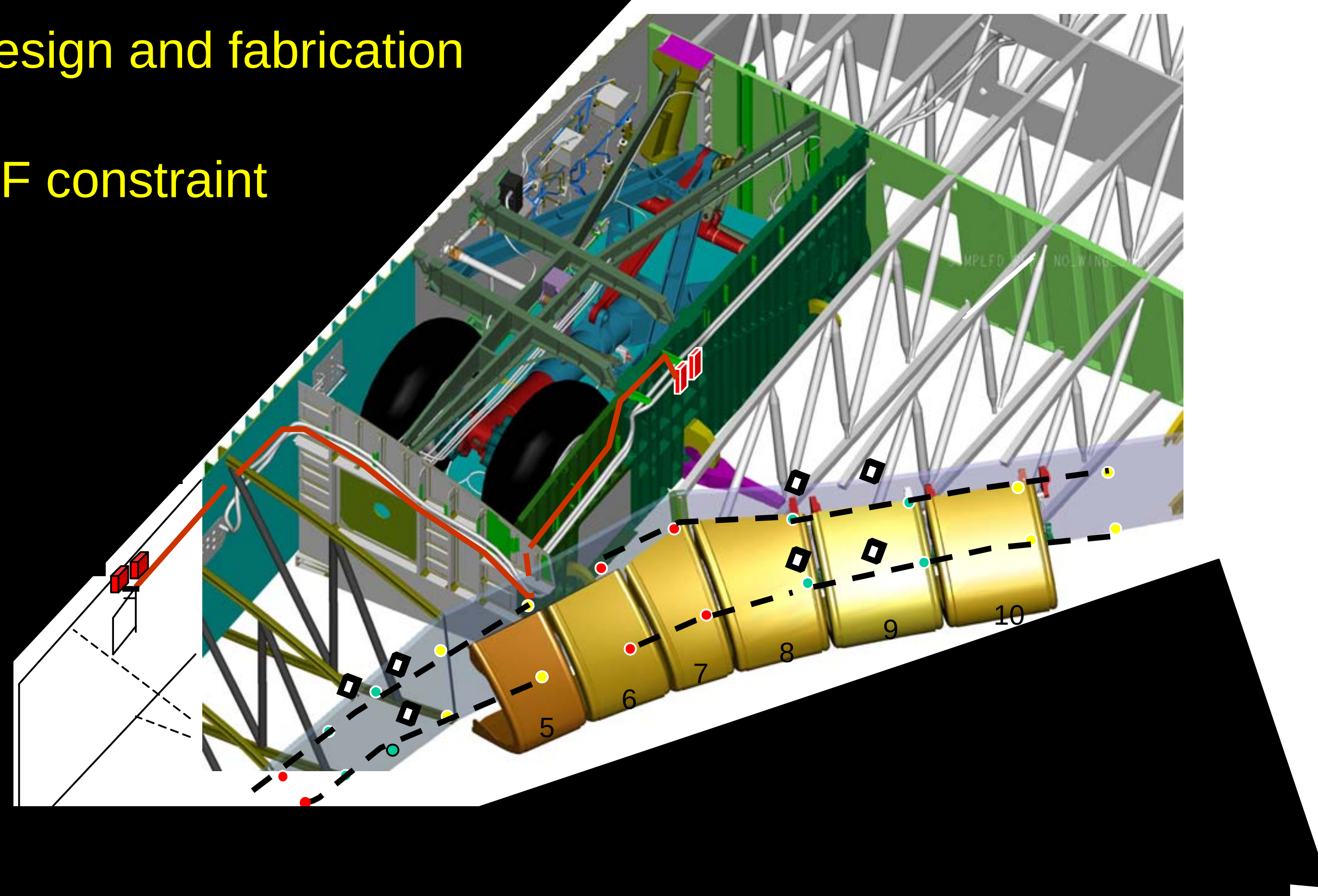
# FY 2005 Shuttle Mission Planning

## Several Factors Bear on Launch Window Determination

- Beta Angle Cut-Outs prohibit specific periods for ISS docking (thermal constraint)
- Launch and ET separation in daylight conditions
- Launch on Need (STS-300) vehicle available for call-up within 90 days
- De-conflicting from Soyuz launch windows

# RTF Planning
## Orbiter Enhancement

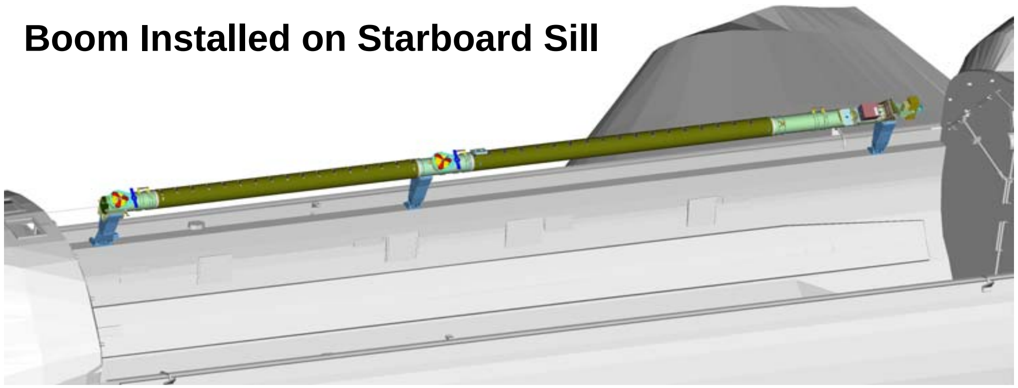
- Program adding Wing Leading Edge instrumentation
- Impact Monitoring System with 92 sensors per wing
- Test articles in design and fabrication
- System not a RTF constraint

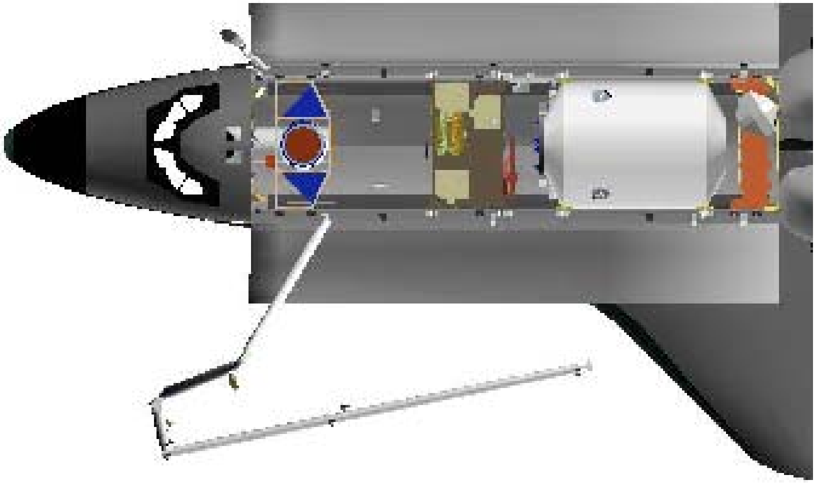


# RTF Planning
## On-Orbit Inspection

- New boom for Shuttle system for TPS inspection
- Attaches to the existing Shuttle's robotic arm
- Boom mounted television/laser sensors
- System compliments other RTF initiatives to understand TPS condition post-launch
- Boom system currently on critical path

**Boom Installed on Starboard Sill**

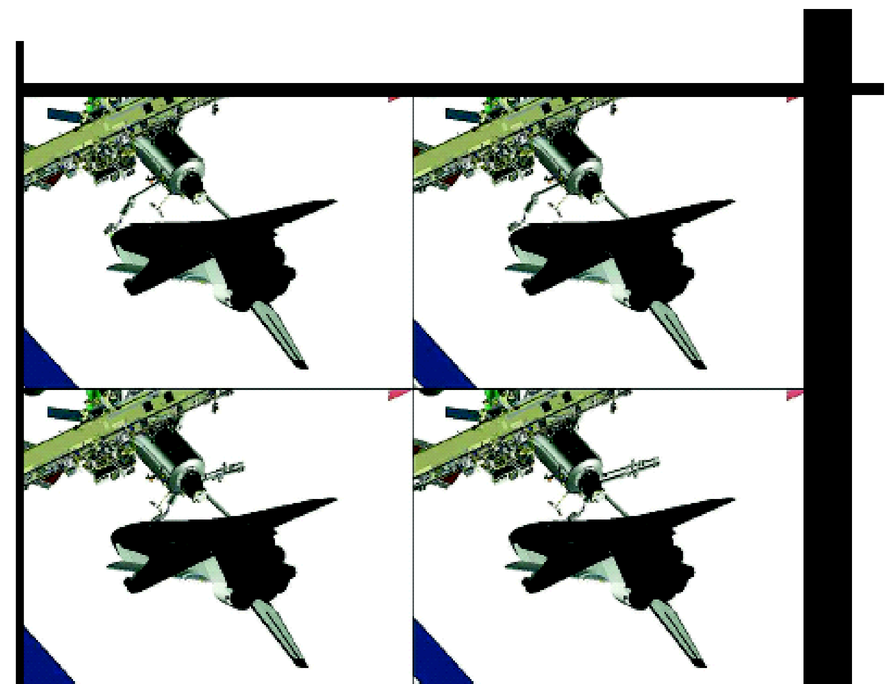




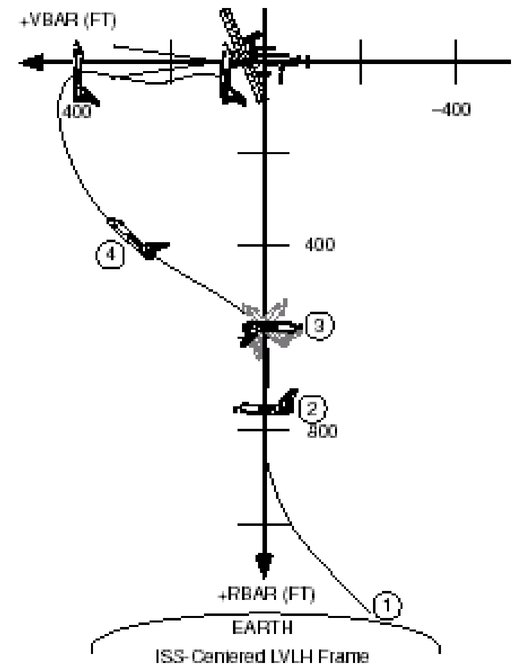
# RTF Planning

## On-Orbit Inspection

- Various techniques being considered
- Techniques for conducting inspection at ISS under study
- ISS crew with on-board cameras may provide additional Shuttle TPS evaluation
- Evaluating use of Shuttle and Station robotic arms to facilitate 100% TPS inspection capability



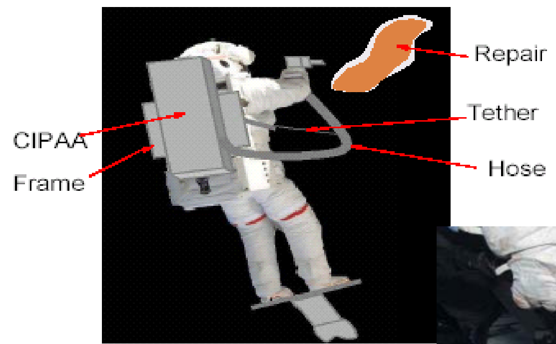
Orbiter Pitch-Around for Inspection and approach to International Space Station

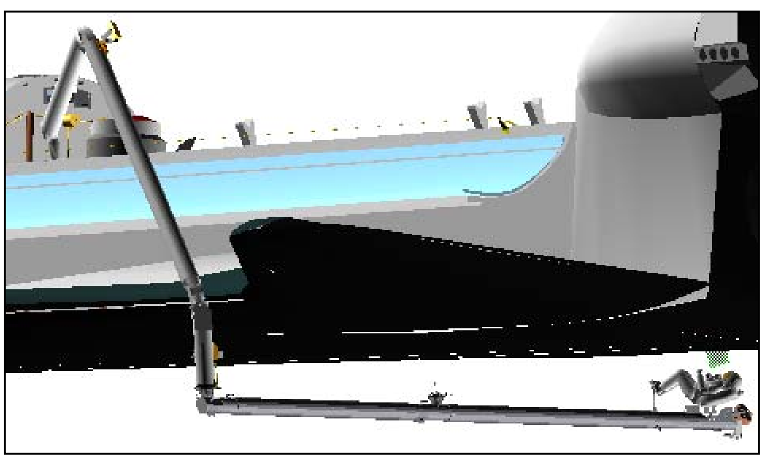



| | EVENT |
|---|---|
| 1 | 1000 FT RANGE RATE GATE (RDOT = −1.3 FPS) TRANSITION TO LOWZ |
| 2 | ORBITER ACQUIRES RBAR |
| 3 | 600 FT (RDOT = −0.1 FPS BEGIN 1 DEG/SEC POSITIVE PITCH AUTO MNVR: MODE TO FREE DRIFT TO PROTECT ISS FROM ORBITER PLUME LOADS AND CONTAMINATION |
| | ISS PHOTOGRAPHIC SURVEY OPPORTUNITY FROM U.S. LAB WINDOW |
| | RESUME ATTITUDE HOLD AS ORBITER RETURNS TO RBAR ATTITUDE AND PILOT BACK TO NOMINAL APPROACH PROFILE |
| 4 | TORVA (TWICE ORBITAL RATE RBAR TO VBAR APPROACH) |

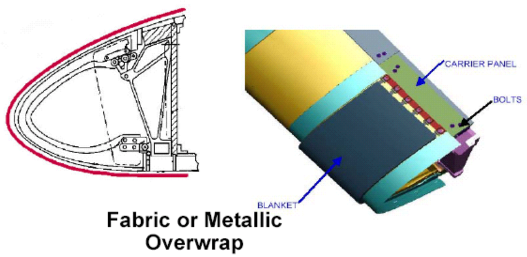
# RTF Planning
## On-Orbit Repair

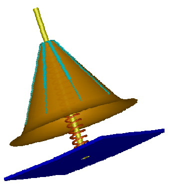
- Various approaches being considered
- Tile repair concept well-defined; cure in-place ablator (CIPA) and application tools in development
- RCC repair tools still in conceptual phase
- First flight to demonstrate TPS repair capabilities



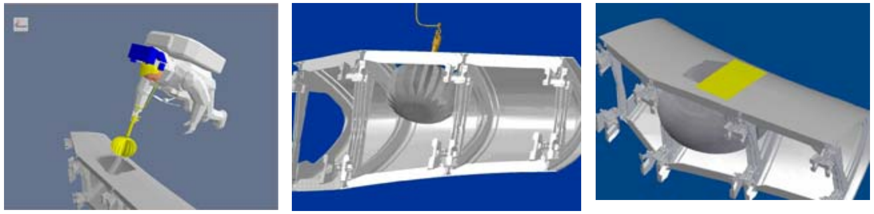
Wrap Concept



Plug Concept

Fill Concept



Insert Inflate Fill

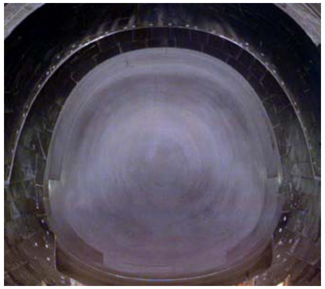
# RTF Planning
## Orbiter Processing

- Reinforced Carbon-Carbon Wing Leading Edge panels removed and inspected; Nose Caps removed and inspected

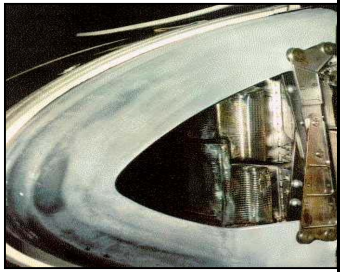
- Discovery Rudder Speed Brake actuators inspected for corrosion, grease degradation and gear alignment – has become a fleet issue

- Wire and Flex Hose Inspections conducted on both Orbiters; repairs in work

- Discovery tiles inspected for de-bonds and replaced as necessary

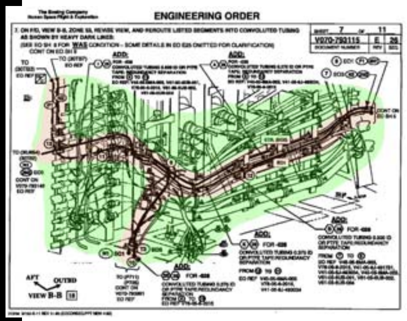


Orbiter Nose Cap



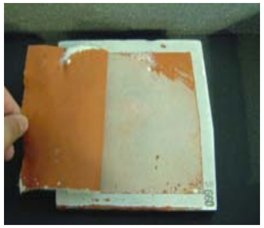
Wing Leading Edge

Rudder Speed Brake Actuator



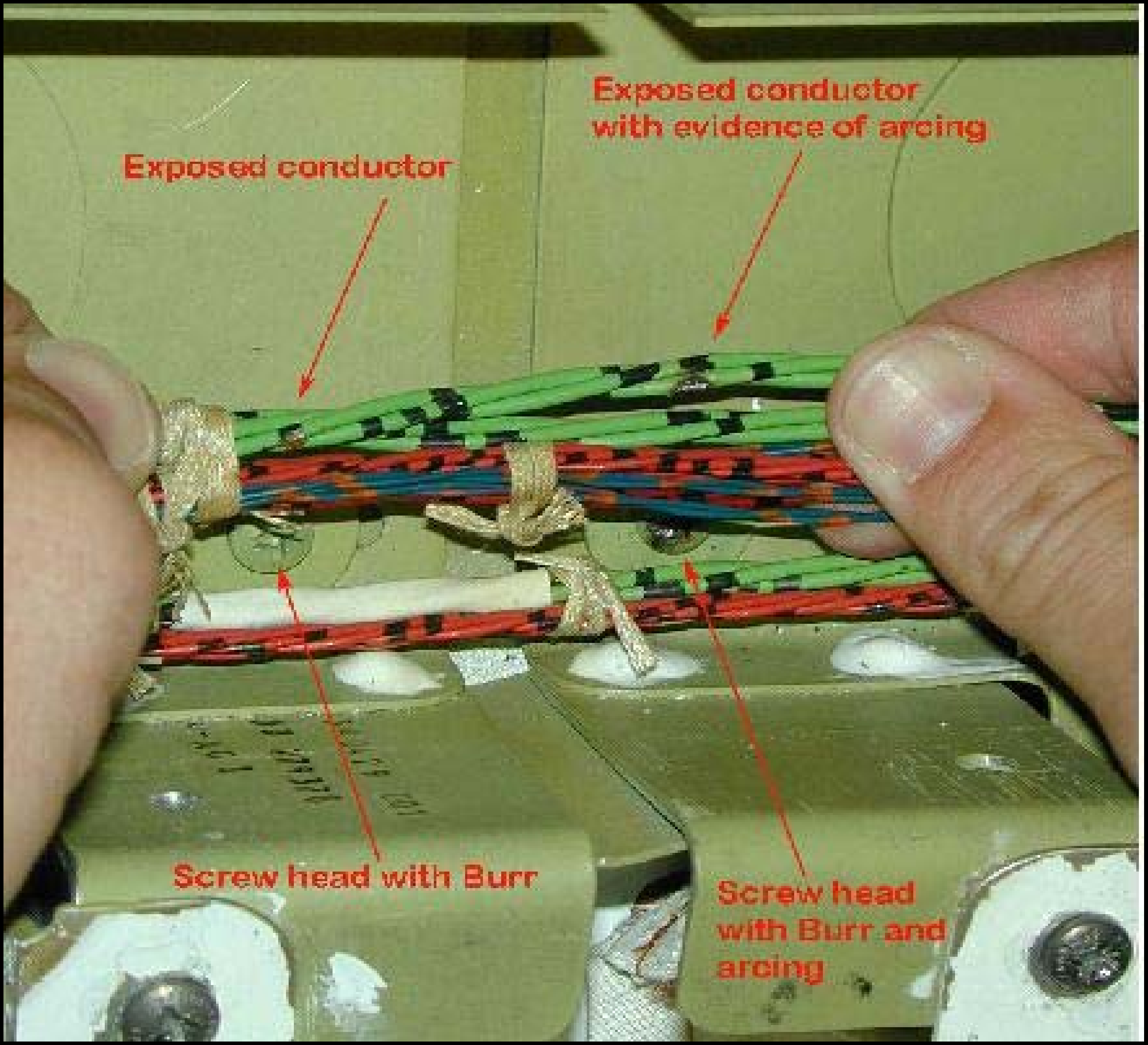

Orbiter Wiring Inspections

Flex Hose Inspections



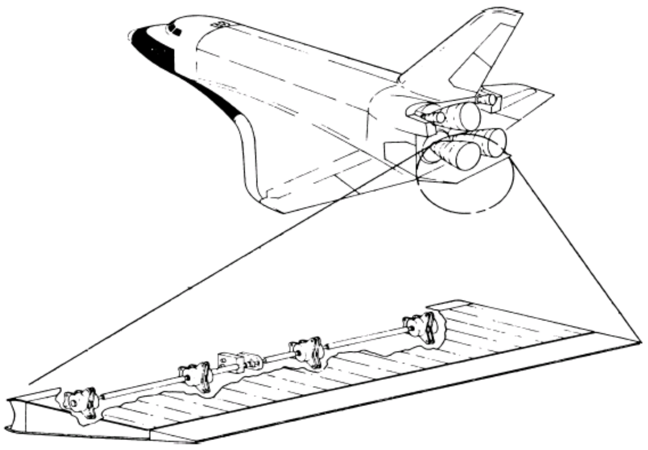
Tile Bond Anomaly

# Wiring

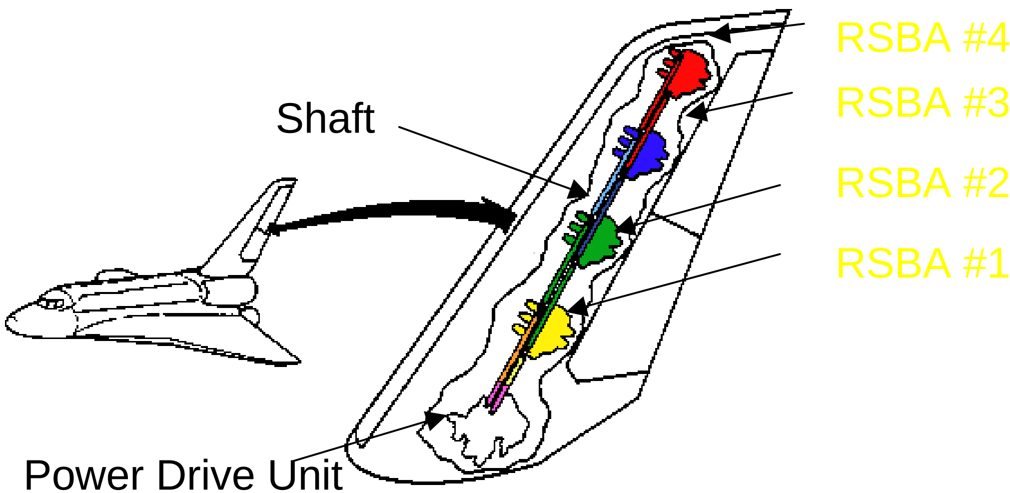

Exposed conductor
with evidence of arcing
Exposed conductor
Screw head with Burr
Screw head
with Burr and
arcing

# Rudder Speed Brake (RSB) Actuators

*Background:* During the OV-103/Discovery Orbiter Maintenance Down Period (Summer of 2003), Corrosion was found on the Orbiter's Body Flap actuators



- Since the Body Flap actuators and Rudder Speed Brake (RSB) actuators were fleet leaders (most flight time), decision was made to also remove the RSB actuators and inspect for corrosion
  - All 4 RSB actuators appeared to have corrosion and were sent to the vendor for further inspection and refurbishment as required

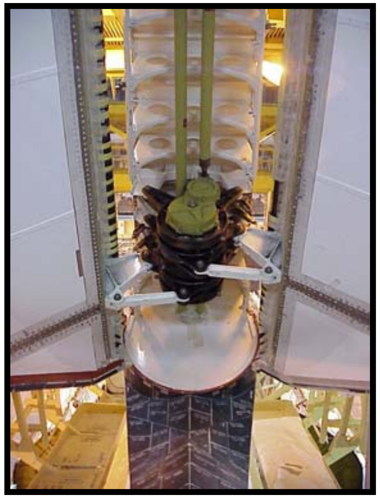



# Rudder Speed Brake (RSB) Actuators

- Decision was made to install the spare RSB actuators while the other units were undergoing vendor inspection
  - Issue was raised about whether the grease in the spares had degraded and might pose a threat if re-installed – independent analysis initiated

- While the RSB actuators were undergoing vendor inspection, one of the actuators was found to have an improperly installed planetary gear

*Result: The improperly installed planetary gear led to a decision to look at the RSB actuators in all three vehicles and determine if there were other planetary gears improperly aligned. This had a significant impact on being able to meet a fall 2004 launch date.*



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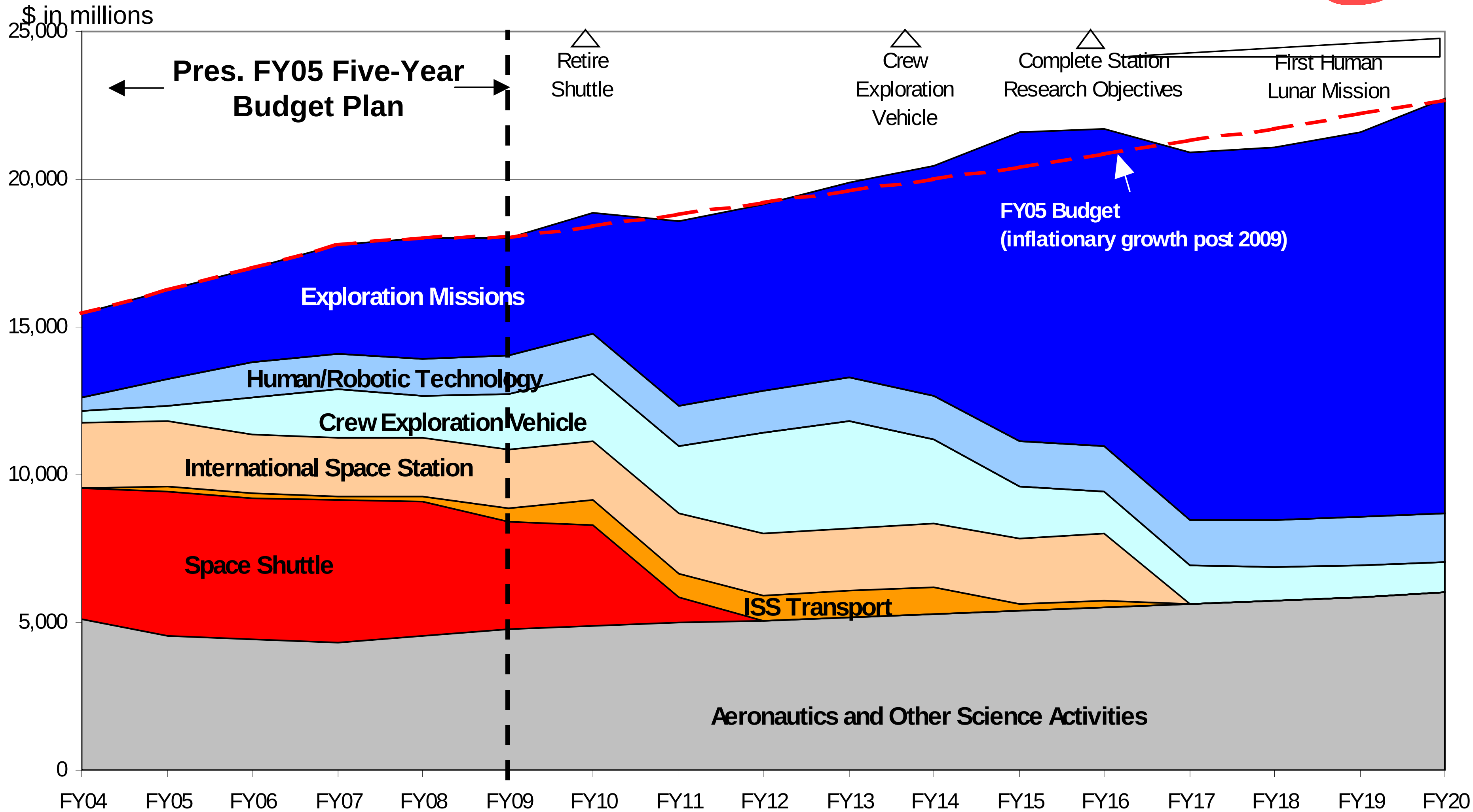
# Cost

- Funding the Return to Flight work
  - Supplemental money
  - Release of unused operations budget

- In the face of a renewed engineering challenge, workforce is expanding in a permanent manner to significantly improve safety

- Next challenge will be cost containment
  - Challenge of maintaining engineering excellence in the face of a future falling budget

# Strategy Based on Long-Term Affordability




NOTE: Exploration missions – Robotic and eventual human missions to Moon, Mars, and beyond
Human/Robotic Technology – Technologies to enable development of exploration space systems
Crew Exploration Vehicle – Transportation vehicle for human explorers
ISS Transport – US and foreign launch systems to support Space Station needs especially after Shuttle retirement

# Schedule

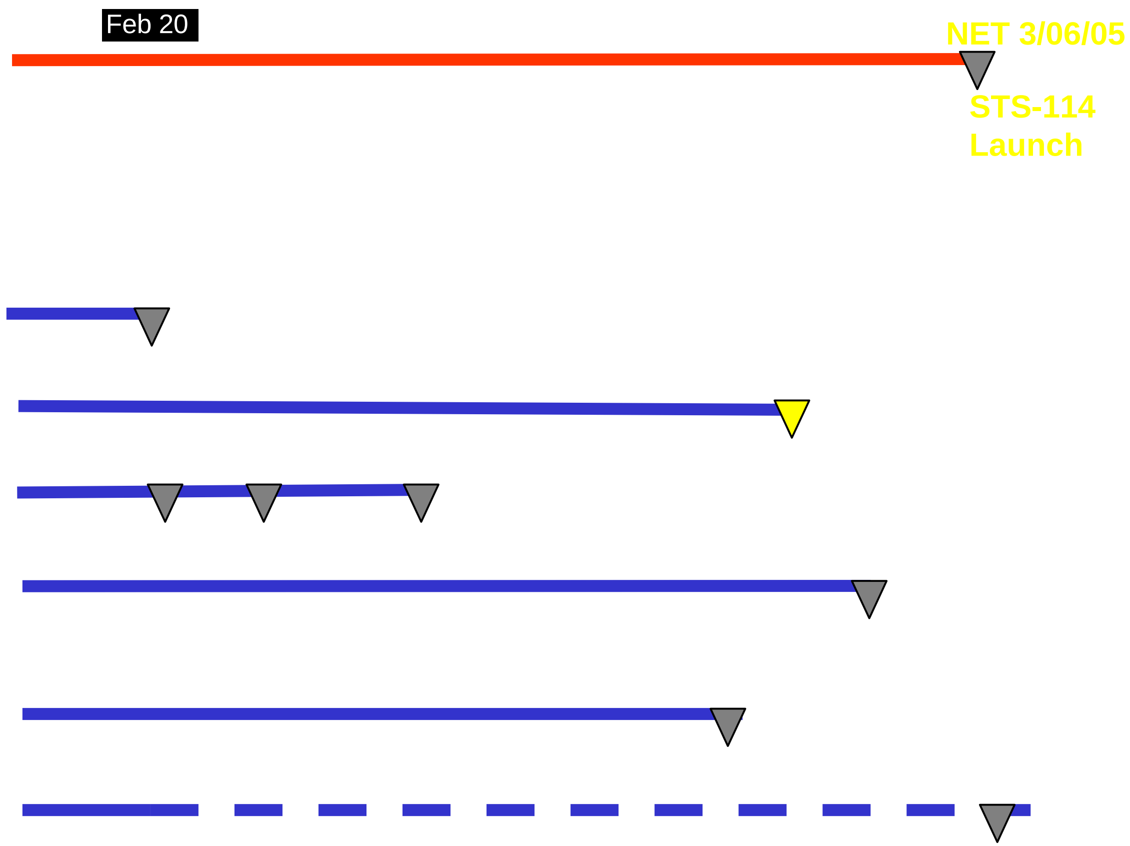
- Currently, the Space Shuttle Program schedule is being driven by the time required to make the safety of flight changes
- Schedule is not a consideration in the classic Project Management sense
- The Mission driving objective is to fly before the International Space Station suffers a serious problem

*WHEN IS THAT?*

- Current safety milestones result in a Return to Flight date no earlier than March 6, 2005
- Our goal is to fly as soon as it is safe to do so to achieve oujr mission objectives

# RTF Planning Focus

## OV-103/Discovery Critical Path Assessment

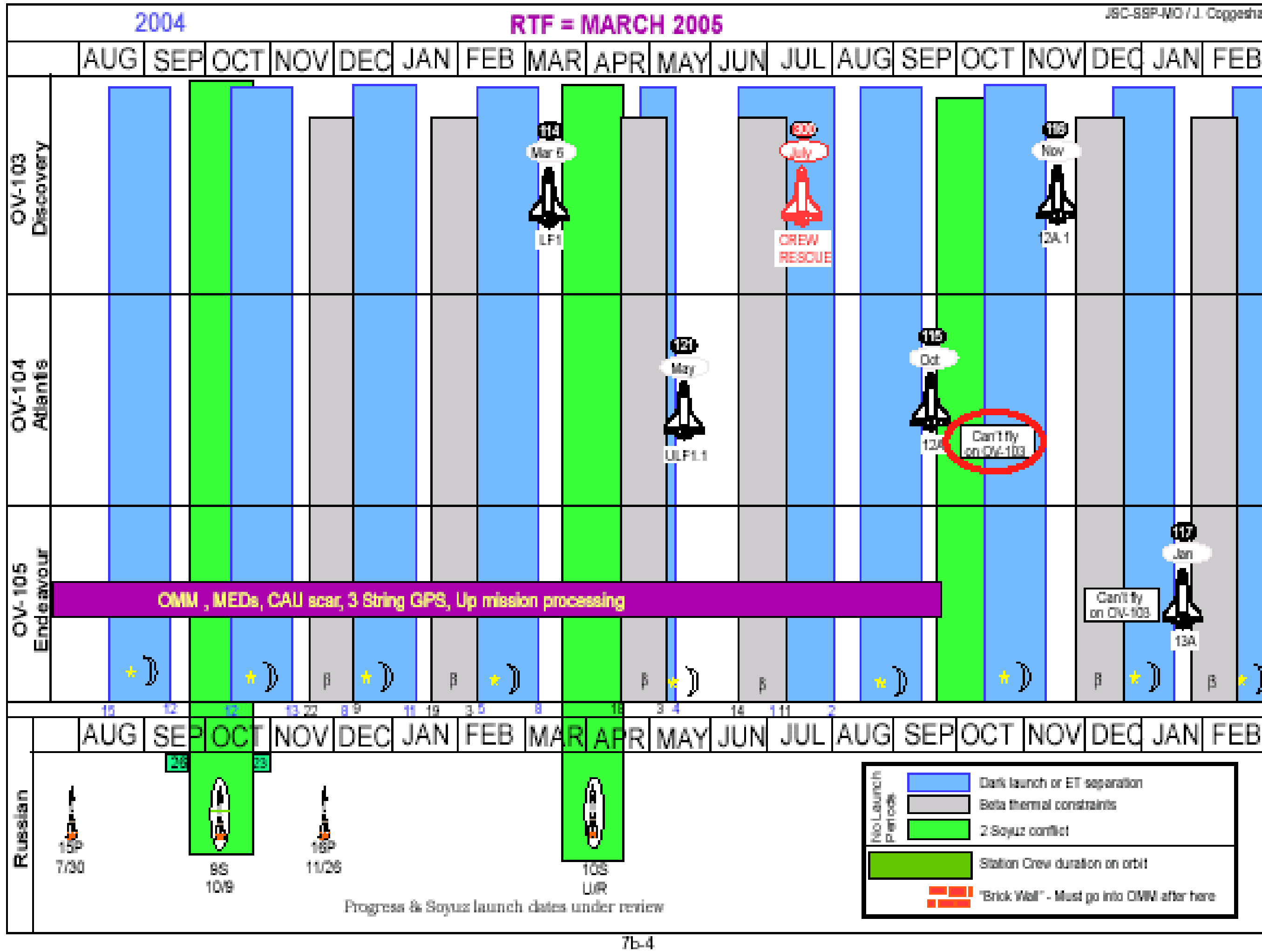



Key:
- Activity has Occurred
- Activity Scheduled to Occur
- Critical Path
- Schedule in Jeopardy

Data Sources
1. USA Schedule Status 2/20/04
2. Feb 19 SFLC Meeting
3. Shuttle Program Reviews

# FY 2005 Shuttle Mission Planning

- 3 missions to ISS
- STS-114 and STS-121 may have mission emphasis on demonstrating RTF capabilities
- February 19 Space Flight Leadership Council announced new target launch window of NET March 6 – April 18, 2005
- RTF remains milestone driven



# Management Challenges

- Culture change required
  - Space Shuttle is not an “operational” vehicle
    - It is experimental/research and development
  - Worker concerns are not to be dismissed by management
  - Additional engineering oversight of the process is required

- 13 Separate Independent Review Teams overseeing Space Shuttle Return to Flight
  - NASA Office of Inspector General has 17 audits of RTF in progress

- New Independent Technical Authority to oversee any “waivers” from standards
  - Over 5,6000 waivers in the Space Shuttle system today
  - No demarcation b between waivers to standards, safety, or other requirements

# Origins of Standards and Requirements

FEDERAL LAWS
EXECUTIVE ORDERS
FEDERAL REGULATIONS
OSHA ITAR USAF/RANGE EPA

*INNUMERABLE*

NASA STANDARDS
NPG, NPR, NPD, NMI

*110 TITLES*

KSC STANDARDS | JSC STANDARDS | MSFC STANDARDS | SSC STANDARDS

*~45,000 STANDARDS*

~~SSP LEVEL I REQUIREMENTS~~

*RETIRED*

SSP LEVEL II REQUIREMENTS
NSTS 07700 PROGRAM REQUIREMENTS
INTERFACE CONTROL DOCUMENTS
EMI REQUIREMENTS
LAUNCH COMMIT CRITERIA
FLIGHT RULES
OPERATIONS MAINTENANCE REQUIREMENTS

*34 VOLUMES*

SSP LEVEL III REQUIREMENTS

# Why is it so hard?

*Why is it so hard?*

*Why does it cost so much?*

*Compare space travel within aviation - compare the Space Shuttle to a Boeing 737*

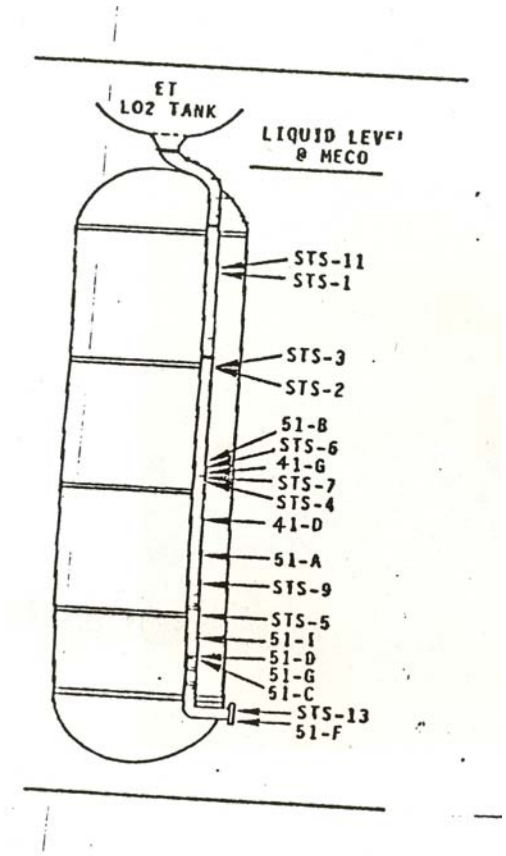

# Comparison of the Space Shuttle to a Boeing 737

| | | |
|---|---|---|
| 122 feet | ***Length*** | 138 feet |
| 78 feet | ***Wingspan*** | 112 feet |
| 173,500 pounds | ***Empty (dry) weight*** | 93,680 pounds |
| April 12, 1981 | ***First flight*** | B737-100 April 9, 1967<br>(-900 Nov 20, 1997) |
| To low earth orbit:<br>56,000 lbs<br>(including crew of 7 & provisions) | ***Payload*** | 52,500 pounds<br>Crew of 2 + 189 Passengers |
| **SHUTTLE EXTERNAL TANK:**<br>**DRY 66,000 LBS; LOADED 1,655,600 LBS**<br>**SHUTTLE SRB (EACH):**<br>**EMPTY 192,000 LBS; LOADED 1,292,000 LBS**<br>**SHUTTLE SYSTEM DRY WEIGHT:**<br>**173,500+66,000 + 192,000 + 192,000 = 623,500 LBS**<br>**ORBITER ONBOARD PROPELLANT LOAD (OMS + RCS):**<br>**23,876 + 7,256 = 31,091 LBS**<br>**SHUTTLE SYSTEM PROP WT:**<br>**1,100,000 + 1,100,000 + 1,589,600 + 31,091 = 3,821,000 LBS** | ***Fuel*** | 6,875 US GAL = 55,000 pounds |

# Comparison of the Space Shuttle to a Boeing 737

- TOTAL SHUTTLE VEHICLE WEIGHT AT LIFTOFF: 4.5 MILLION LBS
- 85% IS PROPELLANT
- 14% IS VEHICLE STRUCTURE
- 1.3% IS PAYLOAD AND CREW
- PROPELLANT RESERVE AT MECO --- 2,300 LBS = 00.060

- B737 MAX TAKEOFF WEIGHT 174,200 LBS
- 31% IS FUEL
- 54% IS VEHICLE
- 30% IS PAYLOAD (passengers, crew, baggage)
- FAA REQUIRED FUEL RESERVE: 45 MINUTES LOITER PLUS DIVERT



# Comparison of the Space Shuttle to a Boeing 737

| | | |
|---|---|---|
| 17,500 MPH<br>(M=25 at 400,000 feet) | | M 0.82 |
| Zero payload<br>600 N. Miles<br>(3,600,000 feet) | | 41,000 feet |
| Average Trip Distance<br>4 Million miles<br>(14 days) | | 3,158 statute miles<br>(6 hours) |
| 6,750,000 pounds | | 2CFM56-7B26 engines<br>26,300 pounds |

*Why so much difference?*

# Energy for Spacecraft vs Aircraft

| | |
|---|---|
| Typical commercial airline cruise: | 30,000 ft (5 N.MI.) at 500 MPH |
| Orbital spacecraft minimum: | 100 N. MI. at 17,500 MPH |

**$E = PE + KE = m\ h\ gc + \frac{1}{2}\ m\ v^2$**

**Energy = Mass X Altitude X Gc + ½ Mass X Velocity Squared**

FOR THE SAME MASS

- Altitude difference: 20 times greater (5 miles vs 20 miles)
- Potential energy difference: 20 times greater

- Velocity difference squared is $(17{,}500)^2 / (500)^2$
- Kinetic energy difference: 1000 times greater

***If it was easy, everyone would be doing it!***

# What About Re-Entry?

Commercial aircraft land with what they take off with
Spacecraft, until the Space Shuttle, do not

97% of all orbital launches recover --- nothing

Soyuz can return 50 kg of scientific equipment and experimental results

Apollo could bring back 250 pounds of lunar rocks, film, experiments

Space Shuttle can return 30,000 pounds of payload, safely to the earth

# What About Re-Entry?

The Law of Conservation of Energy

Everything that goes into putting the Space Shuttle into orbit (4+ million pounds of high energy chemicals), must be removed during re-entry

Orbital velocity is approximately 25,600 FPS

Deorbit burn changes velocity by approximately 300 FPS

Main gear touchdown to wheel stop - brakes, drag chute, speed brakes - remove approximately 300 FPS

25,000 FPS = 98% of the velocity = 99.96% of the kinetic energy – removed by air friction alone

100% of the potential energy removal is accomplished by air friction